Early Structural Changes of Engineered Soils in Bioretention Cell

Premiers changements structurels des sols artificiels dans un ouvrage de biorétention

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RÉSUMÉ

Les sols artificiels jouent un rôle important dans l'hydrologie urbaine, notamment dans le fonctionnement des toitures végétales et des aménagements de biorétention des eaux pluviales. L'infiltration de l'eau, le transport des colloïdes et le transport de la chaleur sont affectés par les changements dans la géométrie du système poreux, notamment en raison du développement de macropores et de l'obstruction par les particules. Le processus de pédogenèse est souvent plus rapide que dans les sols naturels en raison des charges plus élevées en particules et des régimes hydrologiques extrêmes. Dans le projet présenté, nous évaluons les changements temporels de la structure des sols artificiels dans des aménagements de biorétention typiques, au moyen d’expériences sur le terrain et en laboratoire. L'objectif est de mettre en lumière les évolutions dans la performance des ouvrages de biorétention en analysant les changements structurels des sols à l'échelle microscopique, à l’aide de méthodes invasives et non-invasives. Les résultats de la recherche permettront d'améliorer les procédures de conception et de gestion des aménagements de biorétention.

ABSTRACT

Engineered soils play an important role in urban hydrology e.g. in the functioning of green roofs and stormwater bioretention beds. Water infiltration, colloid transport and heat transport are affected by changes in pore system geometry particularly due to development of macropores and clogging by particles. The rate of pedogenesis is often faster than in natural soils due to higher loads of particles as well as by extreme water regimes. In the presented project we assess the temporal changes of soil structure of engineered soils in typical bioretention beds by conducting field scale and laboratory experiments. The aim is to elucidate changes in bioretention cell performance by studying the structural changes of soils at the microscale by invasive and noninvasive methods. The outcomes of the research will lead to improved design and management procedures for and bioretention beds.

KEYWORDS

Bioretention cell, Computed tomography, Soil structure, Technosol, Water regime.

1 INTRODUCTION

Intense urban population growth is associated with negative water-related environmental effects. Along with ongoing urbanization the imperviousness of watersheds, the volume of runoff reaching stormwater sewers, and eventually receiving waters, has increased dramatically during past decades. Next to the hydraulic load, the surface runoff also threatens the quality of water resources by carrying pollutants from roads, parking lots, and rooftops to local waterways. As a consequence of fast runoff from urban areas, ground water levels drop, and the resulting lack of water available for evapotranspiration, in combination with the high proportion of impervious surfaces contributes to the development of urban heat islands (Rizwan et al., 2008). Low Impact Development (LID) or Water Sensitive Urban Design (WSUD) approaches (Fletcher et al., 2015) contribute to mitigation of these adverse effects of urbanization, by improving the retention of stormwater close to its source, removing contaminants from storm water, and enhancing groundwater recharge and evapotranspiration. Bioretention cells are typical examples of LID approaches.

The efficiency of bioretention cells depends on the physical and chemical properties of the soil, which are, in the case of engineered soils, a function of its initial composition and subsequent soil pedogenesis (Jangorzo et al., 2013; Scalenghe and Ferraris, 2009; Sere et al., 2012). Pedogenesis determines the development of soil structure, changes in organic matter content, formation of macropores, clogging of pores by particles, and alterations of soil wettability. Therefore, for the successful design and long term reliable performance of bioretention cells, a detailed knowledge of evolution of transport processes in engineered soils is needed (Dietz, 2007). Noninvasive visualization methods such as computed microtomography (CT), are an effective mean of soil structure assessment. X-ray CT is capable to investigate soil in terms of structure development, pore clogging and pore geometry deformations.

The aim of the presented research is to experimentally enlighten the water and heat transport processes in the bioretention soil. In particular, we aim at relating the changes in performance of the bioretention cell to the changes in the structure of the soil that form a filter layer of the bioretention cell.

2 MATERIALS AND METHODS

Two identical experimental bioretention cells were constructed in December 2017. The first bioretention cell collects the stormwater from the roof of the nearby experimental building (roof area 38 m^2). The second bioretention cell is supplied from a tank using a controlled pump system, which allows to generate artificial rainfall-runoff episodes. The bioretention cell is, conceptually, an infiltration swale, planted in July 2018 by four perennial plants (*Aster novae-angliae “Purple Dome”; Hemerocallis 'Lemon Bells'; Euphorbia amygdaloides; Molinia caerulea*).

Each bioretention cell is 2.4 m wide and 4.0 m long. The maximum depth of the ponding is 0.3 m. The 5 cm-thick mulching layer made of 16/32 mm gravel fraction protects the surface. The 0.3 m- thick filter layer (bioretention medium) is a sand, compost and top soil mixture in 50:30:20 % mass ratio. The 0.27-thick drainage layer consists of 16/32 mm gravel fraction. Drainage layer and the filter layers are separated by a 0.1 m-thick sand layer (0/4 mm fraction) designed for fine particles trapping. The body of experimental bioretention cell is entirely isolated from the surrounding soil by PVC membrane. The effluent is quantified by a tipping bucket flowmeter (PF500 flowmeter, Fiedler AMS, Ltd., Czech Republic).

Soil water content is monitored in each of two bioretention cells in the filter layer by four time-domain reflectometry (TDR) probes (CS635, Campbell Scientific, U.S.A.) connected to the reflectometer (TDR100, Campbell Scientific, U.S.A.). Water content probes are placed in the depth of 0.15 m, below filter layer surface (i.e. 0.2 m below the surface of the mulch layer). Water potential in each bioretention cell is under wet conditions continuously monitored using five tensiometers (T8, Meter Environment, Germany) and at dry conditions by two water potential meters (MPS-6, Meter Environment, Germany) placed in the depth of 0.05 m below the surface of filter layer. The Fig. 1 depicts one of two experimental bioretention cells.

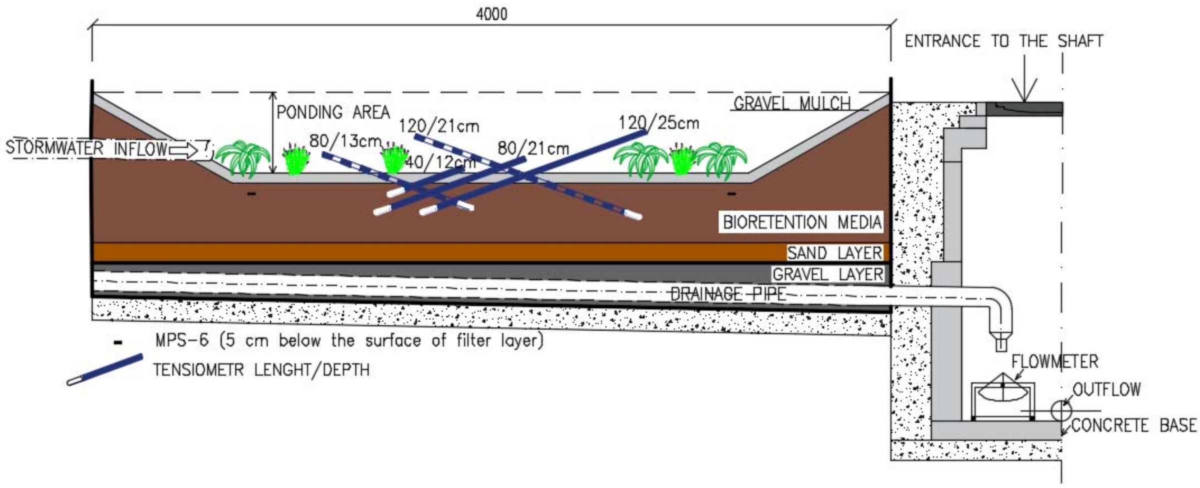

Figure 1. A schema (longitudinal section) of the bioretention cell.

3 RESULTS

Soil hydraulic conductivity and water retention in the filter layer directly depends on the soil's grain size distribution. Grain size analysis was performed on a sample of filter layer material at the beginning of experiments by a combination of sieving and Casagrande's hydrometer methods for particles smaller than 2 mm. The mass fraction of clay (<0.002 mm) is 12 %, mass fraction of silt (0.002–0.05 mm) is 14% and mass fraction of sand (0.05–2 mm) is 74 %. The bulk and particle densities of a filter layer soil is 1264 kg.m^{-3} and 2563 kg.m^{-3} respectively.

Soil water retention curve of the filter layer soil has been determined on replicated undisturbed samples of 143.5 cm^3 taken at time of perennial plant planting by drainage at the sand box (pressure heads between 0 and -50 cm H20) and on a Tempe cell (pressure heads of 100, 300 and 900 cm H20). Average saturated water content of the filter layer soil θ_s is 0.43 m^3.m^{-3}, which is expected value for a sandy soil.

Soil of the first bioretention cell (supplied by the stormwater runoff from the roof) remained relatively wet during whole monitoring period (June – December 2018) as is indicated by water content probes and soil tensiometers. The minimum pressure head of 414.4 cm H_2O was reached on 21.09.2018 in the tensiometer located 13 cm below the surface of the filter layer, which indicates that plants growth was not affected by the water stress. Water content probes indicted volumetric water contents in the range from 0.22 to 0.40 cm during entire monitored period. Runoff from the drainage pipes regularly occurred soon after rainfalls. Six artificial rainfall episodes were performed on the second bioretention cell (connected to the artificial water supply) at the end of the vegetation season. The peak outflow occurred in average 16 minutes after the beginning of the rainfall episode with the simulated rain intensity of 1.54 mm.min^{-1} and 54 minutes after the beginning of the rainfall of intensity 0.59 mm.min^{-1}.

Soil structure is a key property determining the soil hydraulic properties and the bioretetion cell performance. The regular soil sampling program was initiated in 2018 in order to visualize and quantify the soil structure and internal pore geometry of samples. First set of 24 undisturbed samples was collected upon planting in June 2018, while the second set of 23 samples was taken after end of the first vegetation period in November 2018.

Preliminary analysis of the three-dimensional images of samples taken at the beginning and end of the vegetation season show signs of compaction for the latter set of samples. An example of the original, enlarged and segmented vertical cross-sections of the CT images of the samples collected from the first bioretention cell are shown in the Figure 3. The segmented images that visualize the macropore system clearly show less macroporosity in the case of samples taken after vegetation season.

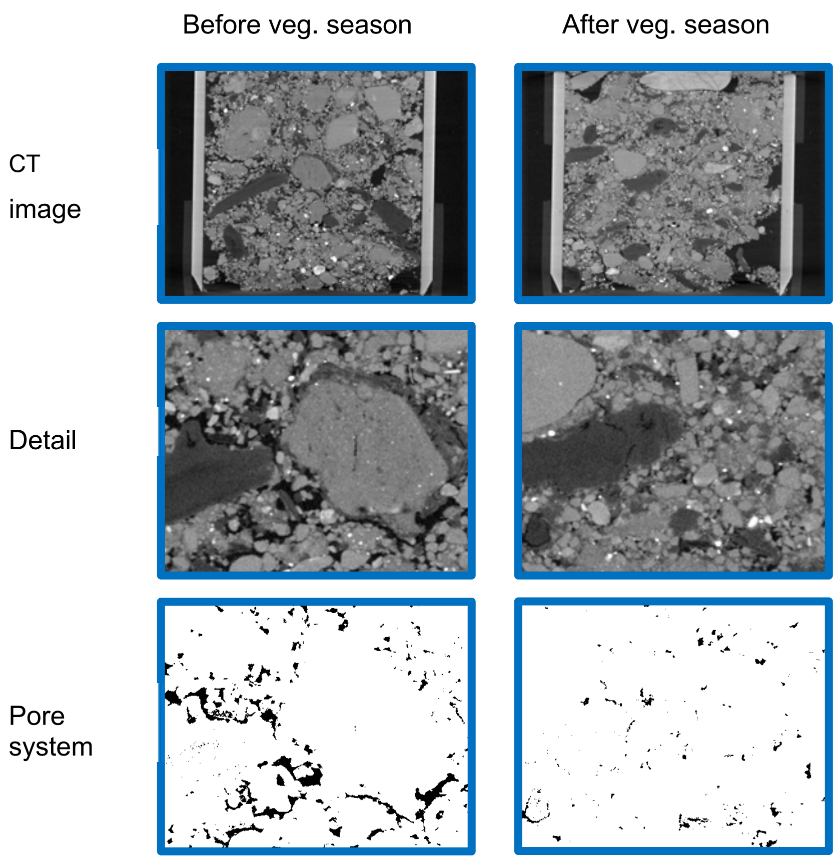

Figure 3. Vertical sections of the three-dimensional X-ray tomographs of two different samples taken from the filter layer of the bioretention cell before and after vegetation season. Original, detailed and segmented 2D sections are displayed in upper, middle and bottom row. In this case the macroporosity decreased from 7 to 2 %.

4 CONCLUSIONS

Experimental facilities dedicated to investigation of the performance bioretention cells has been established. The scheme of soil sampling and soil characterization using standard and noninvasive methods was developed. The on water balance and water potentials recorded during the first seven months of operation already brought important knowledge on rainfall-runoff relationship at the bioretention cell and on the water regime of the filter layer in terms of water availability for plants in European continental influenced climate with warm, dry summers. The preliminary analysis of X-ray CT imaging demonstrates clearly the decrease of macroporosity during the first vegetation season.

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